

# **EXHIBIT A**

DAO 88 (Rev. 1/94) Subpoena in a Civil Case

**Issued by the**  
**UNITED STATES DISTRICT COURT**  
 MIDDLE DISTRICT OF FLORIDA

POWER INTEGRATIONS, INCORPORATED,

Plaintiff,

V.

**SUBPOENA IN A CIVIL CASE**FAIRCHILD SEMICONDUCTOR INTERNATIONAL, INC. AND Case Number:<sup>1</sup> 04-1371-JJF

FAIRCHILD SEMICONDUCTOR CORPORATION, Defendants.

District of Delaware

TO: James D. Beasom

506 South Wildwood Ln,

Melbourne FL 32904-2562

☐ YOU ARE COMMANDED to appear in the United States District court at the place, date, and time specified below to testify in the above case.

PLACE OF TESTIMONY

COURTROOM

DATE AND TIME

☒ YOU ARE COMMANDED to appear at the place, date, and time specified below to testify at the taking of a deposition in the above case.

PLACE OF DEPOSITION

Hilton Melbourne Rialto Place, 200 Rialto Blvd., Melbourne, Florida 32901

DATE AND TIME

January 26, 2006 at 9:00 a.m.

☒ YOU ARE COMMANDED to produce and permit inspection and copying of the following documents or objects at the place, date, and time specified below (list documents or objects):

Documents described in accompanying Schedule A to Amended Subpoena Duces Tecum to James D. Beasom

PLACE

Hilton Melbourne Rialto Place, 200 Rialto Blvd., Melbourne, Florida 32901

DATE AND TIME

January 26, 2006 at 9:00 a.m.

☐ YOU ARE COMMANDED to permit inspection of the following premises at the date and time specified below.

PREMISES

DATE AND TIME

Any organization not a party to this suit that is subpoenaed for the taking of a deposition shall designate one or more officers, directors, or managing agents, or other persons who consent to testify on its behalf, and may set forth, for each person designated, the matters on which the person will testify. Federal Rules of Civil Procedure, 30(b)(6).

ISSUING OFFICER'S SIGNATURE AND TITLE (INDICATE IF ATTORNEY FOR PLAINTIFF OR DEFENDANT)

DATE

January 18, 2006

ISSUING OFFICER'S NAME, ADDRESS AND PHONE NUMBER

Bas de Blank, Orrick, Herrington &amp; Sutcliffe LLP, 1000 Marsh Road, Menlo Park, CA 94025 650.614.7400

Attorney for Defendants Fairchild Semiconductor International, Inc. and Fairchild Semiconductor Corporation

(See Rule 45, Federal Rules of Civil Procedure, Parts C &amp; D on next page)

<sup>1</sup>If action is pending in district other than district of issuance, state district under case number.

AO 88 (Rev 1/94) Subpoena in a Civil Case

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**PROOF OF SERVICE**

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DATE

PLACE

SERVED:

SERVED ON (PRINT NAME)

MANNER OF SERVICE

SERVED BY (PRINT NAME)

TITLE

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**DECLARATION OF SERVER**

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I declare under penalty of perjury under the laws of the United States of America that the foregoing information contained in the Proof of Service is true and correct.

Executed on \_\_\_\_\_

\_\_\_\_\_  
SIGNATURE OF SERVER

\_\_\_\_\_  
ADDRESS OF SERVER

\_\_\_\_\_

## Rule 45, Federal Rules of Civil Procedure, Parts C &amp; D:

## (c) PROTECTION OF PERSONS SUBJECT TO SUBPOENAS.

(1) A party or an attorney responsible for the issuance and service of a subpoena shall take reasonable steps to avoid imposing undue burden or expense on a person subject to that subpoena. The court on behalf of which the subpoena was issued shall enforce this duty and impose upon the party or attorney in breach of this duty an appropriate sanction which may include, but is not limited to, lost earnings and reasonable attorney's fee.

(2) (A) A person commanded to produce and permit inspection and copying of designated books, papers, documents or tangible things, or inspection of premises need not appear in person at the place of production or inspection unless commanded to appear for deposition, hearing or trial.

(B) Subject to paragraph (d) (2) of this rule, a person commanded to produce and permit inspection and copying may, within 14 days after service of subpoena or before the time specified for compliance if such time is less than 14 days after service, serve upon the party or attorney designated in the subpoena written objection to inspection or copying of any or all of the designated materials or of the premises. If objection is made, the party serving the subpoena shall not be entitled to inspect and copy materials or inspect the premises except pursuant to an order of the court by which the subpoena was issued. If objection has been made, the party serving the subpoena may, upon notice to the person commanded to produce, move at any time for an order to compel the production. Such an order to compel production shall protect any person who is not a party or an officer of a party from significant expense resulting from the inspection and copying commanded.

(3) (A) On timely motion, the court by which a subpoena was issued shall quash or modify the subpoena if it

(i) fails to allow reasonable time for compliance,

(ii) requires a person who is not a party or an officer of a party to travel to a place more than 100 miles from the place where that person resides, is employed or regularly transacts business in person, except that, subject to the provisions of clause (c) (3) (B) (iii) of this rule, such a person may in order to attend

trial be commanded to travel from any such place within the state in which the trial is held, or

(iii) requires disclosure of privileged or other protected matter and no exception or waiver applies, or

(iv) subjects a person to undue burden.

## (B) If a subpoena

(i) requires disclosure of a trade secret or other confidential research, development, or commercial information, or

(ii) requires disclosure of an unretained expert's opinion or information not describing specific events or occurrences in dispute and resulting from the expert's study made not at the request of any party, or

(iii) requires a person who is not a party or an officer of a party to incur substantial expense to travel more than 100 miles to attend trial, the court may, to protect a person subject to or affected by the subpoena, quash or modify the subpoena, or, if the party in who behalf the subpoena is issued shows a substantial need for the testimony or material that cannot be otherwise met without undue hardship and assures that the person to whom the subpoena is addressed will be reasonably compensated, the court may order appearance or production only upon specified conditions.

## (d) DUTIES IN RESPONDING TO SUBPOENA.

(1) A person responding to a subpoena to produce documents shall produce them as they are kept in the usual course of business or shall organize and label them to correspond with the categories in the demand.

(2) When information subject to a subpoena is withheld on a claim that it is privileged or subject to protection as trial preparation materials, the claim shall be made expressly and shall be supported by a description of the nature of the documents, communications, or things not produced that is sufficient to enable the demanding party to contest the claim.

# **EXHIBIT B**

**United States Patent** [19]

Beasom

[11] Patent Number: **4,823,173**[45] Date of Patent: **Apr. 18, 1989**[54] **HIGH VOLTAGE LATERAL MOS  
STRUCTURE WITH DEPLETED TOP GATE  
REGION**[75] Inventor: **James D. Beasom, Melbourne  
Village, Fla.**[73] Assignee: **Harris Corporation, Melbourne, Fla.**[21] Appl. No.: **831,384**[22] Filed: **Jan. 7, 1986**[51] Int. Cl.<sup>4</sup> ..... **H01L 29/80**[52] U.S. Cl. .... **357/23; 357/23.8;  
357/35**[58] Field of Search ..... **357/23.8, 22 E, 22 F,  
357/22 G, 35**[56] **References Cited****U.S. PATENT DOCUMENTS**

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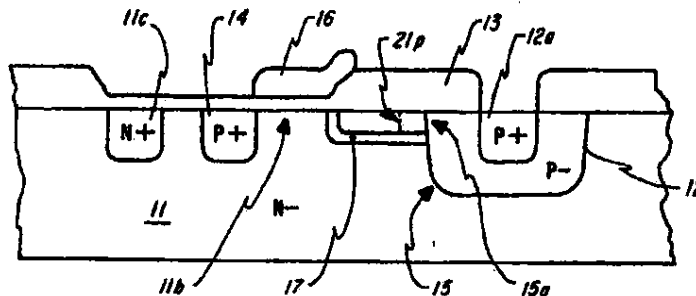
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H. Vacs et al., "High-Voltage, High Current Lateral Devices", 1980 IHDM Conf. Proc., Dec. 8-10, 1980, pp. 87-90.

*Primary Examiner*—Joseph E. Clawson, Jr.*Attorney, Agent, or Firm*—William A. Troner, Charles C. Krawczyk[57] **ABSTRACT**

The present invention provides an improved lateral drift region for both bipolar and MOS devices where improved breakdown voltage and low ON resistance are desired. A top gate of the same conductivity type as the device region with which it is associated is provided along the surface of the substrate and overlying the lateral drift region. In an MOS device, the extremity of the lateral drift region curves up to the substrate surface beyond the extremity of the top gate to thereby provide contact between the JFET channel and the MOS channel.

**19 Claims, 3 Drawing Sheets**

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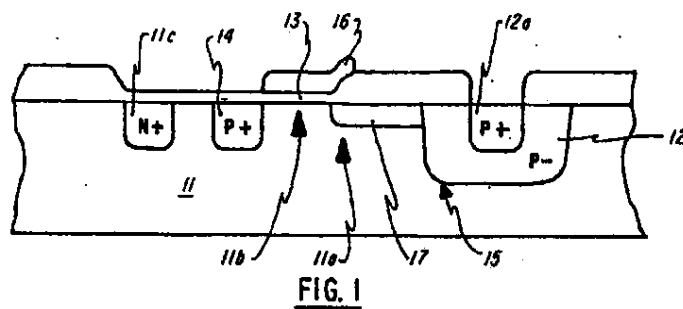


FIG. 1

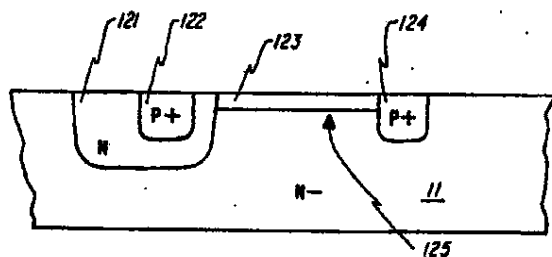


FIG. 2

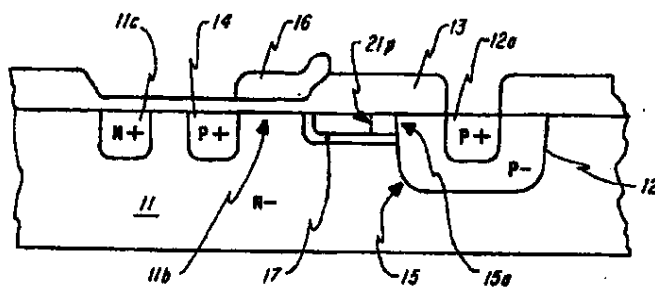


FIG. 3

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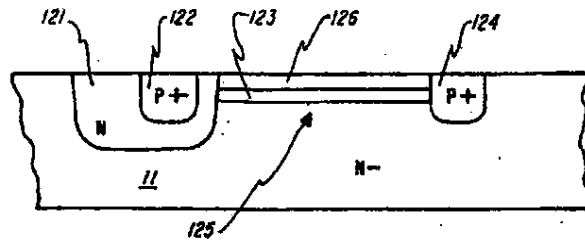


FIG. 6

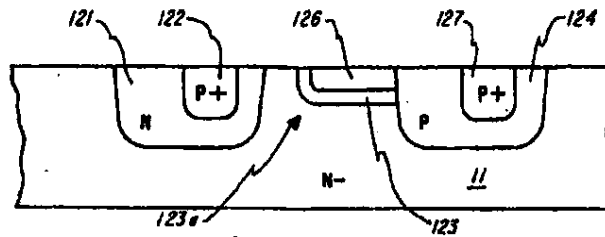


FIG. 7

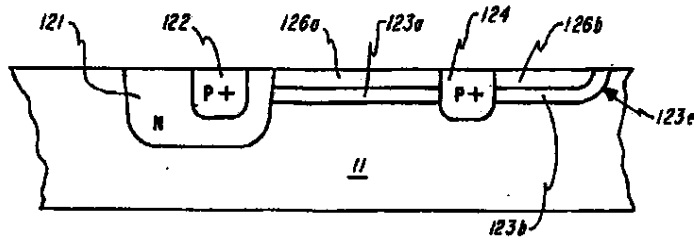


FIG. 8

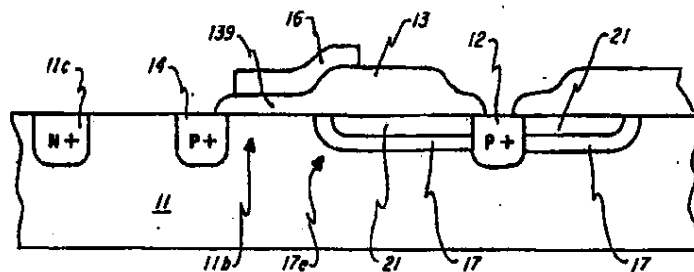


FIG. 9

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# HIGH VOLTAGE LATERAL MOS STRUCTURE WITH DEPLETED TOP GATE REGION

## FIELD OF THE INVENTION

The present invention relates to lateral semiconductor devices and an improved method of making lateral semiconductor devices. More specifically, the invention relates to high voltage lateral devices with reduced ON resistance and a method of making such devices.

Previous high voltage lateral devices include both MOS devices and bipolar transistors. For example, FIG. 1 illustrates a known structure which can be used as a high voltage lateral MOS device. This device is known as a lateral drift region MOS device and is dependent upon the drain body junction 15 as the basic high voltage junction of the device. The drift region 17 is a P region along the top surface of the N<sup>31</sup> substrate 11 and is located so as to lie adjacent the P- drain region 12. The drift region 17 is used to connect the high voltage drain 12 to the gate 16 and source 14. The two contacts, drain contact 12, and body contact 11, are shown for completeness. In the operation of this circuit, the gate 16 and source 14 never assume large voltages relative to the body 11. The drift region 17 serves as a JFET channel with the portion 11<sub>a</sub> of body region 11 underlying the channel acting as a JFET gate. The JFET channel 17 is designed to totally deplete when the drain 12 is reverse biased to a voltage less than the voltage necessary to reach critical field in the channel to body depletion layer. This design preserves the effective high breakdown voltage of drain body junction 15. Also, the source 14 and gate 16 (over the gate oxide 13) are safely shielded from the high drain body voltage by the pinched off JFET channel 17.

The resistance of the lateral drift region JFET channel 17 is in series with the resistance of the MOS channel 11<sub>a</sub>, consequently the total channel resistance of the device is the sum of these two individual resistances. The JFET channel, which must be quite long to sustain high drain body voltages, is often the larger of the two resistance terms. Thus it is desirable to find ways to reduce the resistance of the drift region so that devices of a given size can be made with smaller channel resistance.

FIG. 2 shows a known structure which can be used as a lateral bipolar transistor. Another illustration of such a device is contained in FIG. 7 of U.S. Pat. No. 4,283,236 issued Aug. 11, 1981. Referring to FIG. 2, an N- substrate 11, has an N type emitter shield 121 formed therein and P+ emitter 122 and collector 124 located as shown. Additionally, a P- drift region 123 is provided along the surface of the substrate between the collector 124 and the emitter shield 121. In this device, the total collector resistance is equal to the sum of the resistance across the drift region 123 plus the resistance of the P+ collector between the drift region and the collector contact. In order to provide devices of equal size having a lower collector resistance, it is desirable to find ways to reduce the resistance of the drift region.

In the operation of this device, the drift region extends the collector to the edge of the emitter shield, 121, so that the base width is just that small distance between the adjacent edges of the emitter, 121, and the drift region, therefore providing improved frequency response.

At high base collector voltages the drift region, 123, depletes by JFET action with the N-base, 11, and N

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shield, 121, which is part of the base, acting as gate before critical field is reached just as for the MOS of FIG. 1. This preserves the high breakdown of the structure.

## SUMMARY OF THE INVENTION

The present invention provides a structure having a reduced channel resistance and a process capable of efficiently obtaining the structure of the invention. The reduction in channel resistance is accomplished by providing a top gate which is located between the lateral drift region of the prior art and the surface of the channel region and which may be in contact with the high voltage device region. This top gate allows the total channel doping to be increased because the top gate to channel depletion layer holds some additional channel charge when reverse biased in addition to that held by the bottom gate to channel depletion layer of the prior art structure. The ionized channel impurity atoms associated with this additional channel charge causes the reduction in channel resistance.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section of a known MOS device having typical ON resistance.

FIG. 2 is a cross section of a known bipolar transistor having typical collector resistance.

FIG. 3 is a cross section of an MOS device including the improved drift region and top gate of the invention.

FIG. 4 illustrates optimized process steps for obtaining the desired shape of the top gate and drift region of the invention.

FIGS. 3a and 3b are respectively a top view and is a cutaway perspective view of the body contact extending through the top gate and drift region of the invention.

FIG. 6 is a cross section of a bipolar device made in accordance with one aspect of the invention.

FIG. 7 is a cross section of a bipolar device made in accordance with another aspect of the invention.

FIG. 8 is a cross section of a bipolar device made in accordance with a preferred aspect of the invention.

FIG. 9 is a cross section of an MOS device, including the lateral drift region and top gate of the invention, in a preferred embodiment.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention is described herein with reference to the drawings for both MOS and bipolar applications. FIG. 3 shows an MOS device where P+ drain contact 12a is formed in P- type drain 12, P+ source 14 is formed in the N- body 11 and N+ body contact 11<sub>c</sub> is provided in the N- body 11. The MOS channel region 11<sub>a</sub> is in the N- body 11 below the MOS gate 16. The N type top gate 21 is provided along the surface 11<sub>b</sub> of the body 11 above the P type drift region 17 which acts as a JFET channel. The lateral edge or peripheral edge of both the top gate 21 and drift region 17 extend to the drain body junction 15 and preferably terminate at the junction 15. It is noted that situations may exist where the doping level in the top gate may be sufficiently high so as to render it desirable to provide a shorter top gate having a lateral extension which stops short of contacting the junction 15. In this case care should be taken to insure that any non-depleted portion of the top gate does not result in a breakdown of the top

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gate to drift region junction. Proper doping of the top gate will generally be a sufficient preventative step. Dashed line 21<sub>a</sub> designates the peripheral edge of top gate 21 in an embodiment where the top gate does not extend all the way to the junction 15.

The structure of FIG. 3 provides reduced ON resistance in the JFET channel relative to the prior art lateral drift MOS device as shown in FIG. 1. The reduction in ON resistance is accomplished by providing a structure which can accommodate increased drift region doping without suffering from reduced body to drain breakdown. This is possible because of the provision of the top gate 21. The top gate to channel depletion layer which holds some channel charge when reverse biased, is in addition to the channel charge held by the bottom gate to channel depletion layer of the prior art. This additional channel charge, in the form of ionized channel impurity atoms, results in the reduction in channel resistance. It is possible to provide more than twice the doping level previously acceptable due to the additional ability to hold channel charge. Thus, for a drift region having a doping of  $1 \times 10^{12}$  boron atoms per square centimeter over the drift region surface in a bottom gate arrangement, the present invention will permit  $2 \times 10^{12}$  boron atoms per square centimeter. Thus, the ON resistance will be only half the ON resistance of the prior arrangement.

In order to optimize performance of the structure of the invention, the top gate 21 must be designed differently than an ordinary JFET gate. Top gate 21 should become totally depleted at a body to drain voltage of less than the breakdown voltage of the top gate to drain junction 15<sub>a</sub>. Since top gate 21 is connected to body 11, the voltage at the top gate to drain junction 15<sub>a</sub> will equal the voltage of the body to drain junction 15 voltage and the top gate to drain breakdown voltage should be greater than the voltage at which top gate 21 becomes totally depleted. Additionally, the top gate 21 should totally deplete before the body 11 to channel 17 depletion layer reaches the top gate 21 to channel 17 depletion layer to thereby assure that a large top gate 17 to drain 12 voltage is not developed by punch-through action from the body 11. An ordinary JFET gate never totally depletes regardless of operating conditions.

In addition to the above described characteristics of the device of the invention, it is also desirable to insure that the channel of the JFET drift region contacts the inversion layer MOS surface channel. This can be accomplished as shown in FIG. 4 where an implant mask 50 having a tapered edge 51 is provided over the body 11. An implant aperture 52 is provided in mask 50 at the location where the P drift region 17 and top gate 21 are to be formed. The aperture 52 is shown as exposing the protective oxide 53. Ion implantation is not substantially effected by the oxide 53 due to the oxide thickness of only about 0.1-0.2 micrometers, yet the oxide provides surface passivation for the underlying body 11.

The drift region 17 is ion implanted and because of the graduated thickness of the implant mask 50 (along the edge 51) the depth of the implanted drift region 17 is graduated or tapered. In the illustration, a fairly good rounding of the drift region 17 occurs at the peripheral edges or extremities 17<sub>a</sub>, 17<sub>b</sub> of the region 17. The curved extremity 17<sub>a</sub> is of interest because at this location the channel of the JFET drift region 17 contacts the surface 11<sub>a</sub> of body 11 beyond the end 21<sub>a</sub> of top gate 21 and is desirably beneath the gate 16 of the MOS device. The top gate 21 may be ion implanted into the

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drift region using the implant mask 50 but at an energy level which results in a shallower ion penetration. This tapered profile, particularly if curved, provides improved performance.

In a variation of this method a diffusion process can be used to bring the JFET channel into contact with the surface 11<sub>a</sub> of body 11, and hence insure that the JFET channel will contact the inversion layer MOS surface channel. The lateral drift region 17 and top gate 21 are diffused into the body 11 after initial introduction by ion implant. The doping levels and diffusion times are chosen such that the extremity 17<sub>a</sub> of drift region 17 diffuses beyond the end 21<sub>a</sub> of the top gate 21 and so that the end 17<sub>a</sub> reaches the surface 11<sub>a</sub> of body 11. In practice, this approach can be facilitated by choosing a top gate dopant which has a lower diffusion coefficient than that of the drift region dopant.

The formation of the drift region and top gate may be conveniently carried out by forming a mask over the gate oxide which is present in a lateral MOS application. The MOS gate may be utilized as one delineating edge of the implant for the drift region and top gate and a thick oxide portion surrounding a thinner oxide portion may form the remainder of the implant mask. The thinner oxide portion shall be located such that it extends from beneath the MOS gate to the drain and preferably overlaps the drain. The implant mask 50 illustrated in FIG. 4 is shown as having thin oxide portion 53 being surrounded by the implant mask 50. If the MOS gate 16 shown in dashed lines were used as a portion of the mask 50, the edge of the drift region and top gate would be self aligned with the MOS gate as shown in dashed lines. Then, when diffused, the drift region will extend laterally to a point beneath the MOS gate while the top gate may be formed such that there is little or no lateral overlap with the MOS gate. The extent of lateral diffusion of the top gate is dependent upon the dopant material and processing temperatures following top gate implant. It is noted that there is a separation between the drift region and the source. This separation zone is the location where the MOS channel is located.

The top gate 21 will perform as previously described if it is tied to the body 11. Thus, the top gate 21 and the body which operates as the bottom gate of the JFET channel will be at equal potential. According to the invention, this may be accomplished in a particularly effective manner if the drift region 17 is widened to overlap with the body contact region 11<sub>c</sub>. This is shown in FIG. 5, which shows the overlapping of the top gate 21 and the body contact 11<sub>c</sub> at overlap regions 21<sub>c</sub>, 21<sub>d</sub>. In order for this arrangement to be effective, it is necessary that the body contact 11<sub>c</sub> have a higher dopant concentration than the JFET channel (or drift region) 17 as shown in FIG. 5, to insure that the body contact 11<sub>c</sub> forms a continuous region horizontally and/or vertically through the JFET channel and to the body region 11 from the top gate, 21.

FIG. 5<sub>b</sub> shows a cross section of the structure of FIG. 5<sub>a</sub> taken along dashed line A—A. The body 11 is provided with body contact 11<sub>c</sub> which is located such that the top gate 21 and drift region 17 can be conveniently extended to overlap the body contact 11<sub>c</sub>. The depth of body contact 11<sub>c</sub> may be made greater than the depth of region 17 such that a portion of the body contact 11<sub>c</sub> extends below region 17 and provides contact with the body 11. This arrangement provides a contact portion 21<sub>c</sub> where the top gate 21 is in contact with body

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contact 11. Thus, so long as the body contact doping concentration in region 21, is sufficiently high to overcome the opposite doping in region 17, then a good connection of uniform conductivity type will be provided between the top gate 21 and the body 11. It is also noted that the body contact 11, extends laterally beyond the end of both of the top gate 21 and the drift region 17. The lateral extension of the contact 11, will also provide a structure which results in a good connection of uniform conductivity type from the top gate 21 to the body 11, again, provided that the doping of body contact 11, converts region 21.

Another area where the present invention finds application is in lateral bipolar transistors which employ a lateral drift region. The known structure of FIG. 2 may be improved by providing an N type top gate 126 as shown in FIG. 6. In this arrangement the top gate 126 extends from the collector 124 to the emitter shield 121 along the surface of body 11. The operation of this device is enhanced by the same phenomenon as the lateral drift region of the previously described MOS device. As the base 11 becomes positive relative to the collector 124, the top gate to drift region depletion layer facilitates pinch-off of the drift region. However, as the base 11 becomes more negative the top gate 126 contributes additional surface exposure to the drift region 123 resulting in lower collector resistance.

FIG. 7 shows an improvement over the arrangement shown in FIG. 6. In FIG. 7 the drift region 123 does not extend all the way over to the emitter shield 121. The curved end 123, of the drift region 123 contacts the top surface of body 11. It is noted that in this arrangement, the emitter shield 121 may be omitted.

An additional improvement shown in FIG. 7 is the use of a deep diffusion to form the collector 124 resulting in a significantly increased breakdown voltage. The deep diffusion step may be the same step used for forming the emitter, in which case the collector 124 shown in FIG. 6 would be deeper, or a separate collector implant and diffusion step may be employed and the collector contact 127 may then be formed simultaneously with the formation of the emitter 122. This improvement in junction breakdown voltage is equally obtainable, for example, at the body to drain junction in the MOS devices described previously.

A further extension of the invention which may be used to increase base to collector breakdown voltage for a PNP device is shown in FIG. 8. In addition to the provision of the N type top gate 126, over the P- drift region 123, the top gate and drift region are enlarged to surround the collector 124 and a curved edge 123, is provided at the periphery of the enlarged portion 123, of the drift region. This enlarged portion is designated by reference numerals 123, for the drift region and 126, for the top gate. The collector 124 to base 11 breakdown voltage is increased relative to alternative arrangements because of mitigation of the breakdown reduction due to the junction curvature. The top gate 126, extends to the emitter shield 121 as does the drift region 123. The P+ emitter 122 is formed in the N+ type emitter shield.

FIG. 9 illustrates an extension of the invention with respect to a P channel MOS device similar to the improvement described with respect to the bipolar device shown in FIG. 8. For the MOS device, the P+ drain 12 is surrounded by the P- drift region 17 and N type top gate 21. Around the entire periphery of the drift region there is a curved portion 17, which rounds up to the

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surface of the N- substrate 11 to insure that the JFET channel in the drift region 17 contacts the MOS channel 11, under the MOS gate 16. The drift region 17 extends outward from the entire perimeter of the drain 12. This arrangement mitigates the breakdown reduction due to junction curvature. The P+ source 14 and N+ body contact 11, are shown as is the dielectric 13 which serves as the gate oxide 13, beneath the MOS gate 16.

In both the arrangements shown in FIG. 8 and FIG. 9, the planar diode breakdown improvement created by the drift region acting as a surface layer of the same conductivity type as the collector in FIG. 8 and drain in FIG. 9 and extending out from the perimeter of the collector and drain can be implemented by a single series of process steps. According to the invention, a common set of process steps produces both a suitable breakdown improvement layer and an improved drift region. The breakdown improvement layer is a two layer component.

While the present invention has been described with respect to several preferred manners of implementing the invention, it is to be understood that the claims appended hereto are intended to cover the invention in its broadest sense and are not to be limited to the specific implementations disclosed.

What is claimed is:

1. In a semiconductor device of the type including a lateral drift region of a first conductivity type formed in a body region, said drift region serving as a JFET channel, the improvement comprising:
  - a top gate of a semiconductor material electrically connected to said body region and having a second conductivity type over said drift region to cause depletion of said drift region from the top upon application of a reverse bias voltage to said device, wherein said top gate laterally abuts a device region to form a junction and has a surface area doping density such that said top gate becomes totally depleted at a reverse bias voltage below the reverse breakdown voltage of the top gate to device region junction, and
  - wherein said top gate has a surface area doping density such that it becomes totally depleted at a reverse bias voltage less than the reverse bias voltage at which said drift region becomes depleted.
2. A semiconductor device as claim 1 wherein said drift region as a tapered peripheral edge.
3. A semiconductor device as claimed in claim 2 wherein said top gate has a lateral expanse bounded by said drift region.
4. A semiconductor device as claimed in claim 3 wherein said top gate has a tapered peripheral edge.
5. A semiconductor device comprising:
  - a semiconductor body of a first conductivity type;
  - a first device region of a second conductivity type formed in said body;
  - a second device region of said second conductivity type formed in said body and separated from said first device region;
  - a drift region of said second conductivity type formed in said body between said first and second device regions, separated from said second device region by a separation zone and in contact with said first device region, said drift region having a first side adjacent said body;
  - a top gate of said first conductivity type adjacent a substantial portion of a second side of said drift region and electrically connected to said body;

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wherein said top gate and semiconductor body operable as a top and bottom gate respectively of a JFET channel formed by said drift region;  
 said top gate having a surface area doping density such that it becomes totally depleted at a body to first device region voltage below the voltage at which the body to drift region depletion layer in said first side of said drift region reaches the top gate to drift region depletion layer in said second side of said drift region.

6. A semiconductor device as claimed in claim 5 wherein said first device region is a drain of a lateral drift region MOS device;  
 said semiconductor device further comprising an MOS gate located over said separation zone and overlapping a portion of said drift region.

7. A semiconductor device as claimed in claim 5 wherein said first device region is a collector of a lateral bipolar transistor and wherein said separation zone comprises an emitter shield region of said first conductivity type.

8. A semiconductor device as claimed in claim 5 wherein said drift region and top gate are in contact with said first device region about the entire periphery of said first device region.

9. A lateral MOS structure comprising a semiconductor body of a first conductivity type, source and drain regions of a second conductivity type forming respective source and drain junctions with said body, and a drift region of said second conductivity type, said drift region forming a JFET channel in said body controlled by said semiconductor body which body operates as a JFET gate such that upon application of a reverse bias to said body to drain junction said drift regions becomes depleted, and  
 a top gate of said first conductivity type formed in said drift region and being electrically connected to said body, said top gate having a surface area doping density such that it becomes totally depleted below a body to drain voltage at which said drift region becomes depleted.

10. A lateral MOS structure as claimed in claim 9 wherein:  
 said top gate is laterally spaced from said drain.

11. A lateral MOS structure as claimed in claim 9 wherein:  
 a body contact of said first conductivity type is formed in said body and said top gate overlaps said body contact, said body contact having an impurity concentration higher than the impurity concentration of said drift region.

12. A lateral MOS structure as claimed in claim 9 wherein:

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said drift region and said top gate extend laterally around the entire surface intersection of the drain to body junction to reduce the surface field and thereby increase breakdown voltage of the drain to body junction.

13. A lateral MOS structure as claimed in claim 9 wherein:  
 said top gate totally depletes below a body to drain voltage at which said drift region totally depletes.

14. A lateral MOS structure as claimed in claim 9 wherein:  
 said top gate is formed by an ion implant, and said top gate has a tapered peripheral edge.

15. A lateral MOS structure as claimed in claim 14 wherein:  
 said drift region is formed by an ion implant and said drift region has a tapered peripheral edge.

16. A diode structure comprising:  
 a first semiconductor body of a first conductivity type contained within a semiconductor region of a second conductivity type and forming a diode junction therewith, said semiconductor region having a first dopant concentration,  
 a second body of said first conductivity type contained within said semiconductor region and having a second dopant concentration greater than said first dopant concentration, said second body surrounding the lateral perimeter of said first body and abutting said first body;  
 said second body forming a JFET channel controlled by said semiconductor region which region operates as a JFET gate such that upon application of a reverse bias to said region to first body junction said second body becomes depleted, and  
 a top gate of said second conductivity type formed within said second body and being electrically connected to said first semiconductor region, said top gate having a dopant concentration such that upon application of said reverse bias, said top gate becomes totally depleted before said second body becomes depleted.

17. In a diode structure as claimed in claim 16, the improvement comprising:  
 a tapered peripheral edge for said top gate.

18. In a diode structure as claimed in claim 17, the improvement comprising:  
 forming said tapered peripheral edge by implanting said top gate using an implant mask with a tapered edge.

19. In a diode structure as claimed in claim 16, the improvement comprising:  
 forming a tapered peripheral edge for said second body by implanting said second body using an implant mask with a tapered edge.

\* \* \* \* \*

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# **EXHIBIT C**

# United States Patent [19]

## Beasom

US005264719A

[11] Patent Number: 5,264,719

[45] Date of Patent: Nov. 23, 1993

### [54] HIGH VOLTAGE LATERAL SEMICONDUCTOR DEVICE

[75] Inventor: James D. Beasom, Melbourne Village, Fla.

[73] Assignee: Harris Corporation, Melbourne, Fla.

[21] Appl. No.: 705,509

[22] Filed: May 24, 1991

#### Related U.S. Application Data

[63] Continuation of Ser. No. 242,405, Sep. 8, 1988, abandoned, which is a continuation-in-part of Ser. No. 831,384, Jan. 7, 1986, Pat. No. 4,823,173.

[51] Int. Cl.<sup>3</sup> ..... H01L 29/80

[52] U.S. Cl. .... 257/335; 257/336; 257/339

[58] Field of Search ..... 357/38, 55, 23.8, 46

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Primary Examiner—Rolf Hille

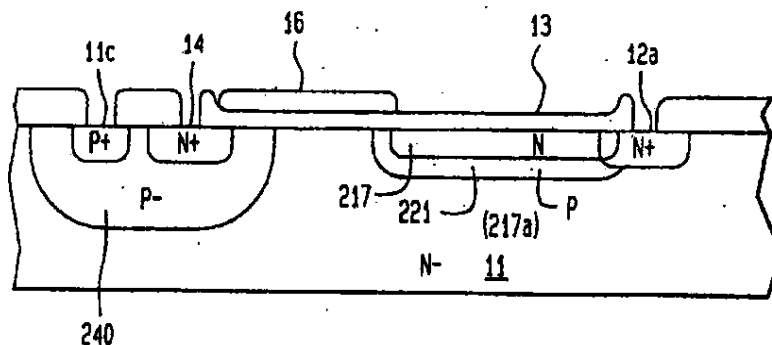
Assistant Examiner—Roy Potter

Attorney, Agent, or Firm—Evenson, Wands, Edwards, Lenahan &amp; McKeown

#### [57] ABSTRACT

The present invention provides an improved lateral drift region for both bipolar and MOS devices where improved breakdown voltage and low ON resistance are desired. A top gate of the same conductivity type as the device region with which it is associated is provided along the surface of the substrate and overlying the lateral drift region. In an MOS device, the extremity of the lateral drift region curves up to the substrate surface beyond the extremity of the top gate to thereby provide contact between the JFET channel and the MOS channel.

42 Claims, 7 Drawing Sheets



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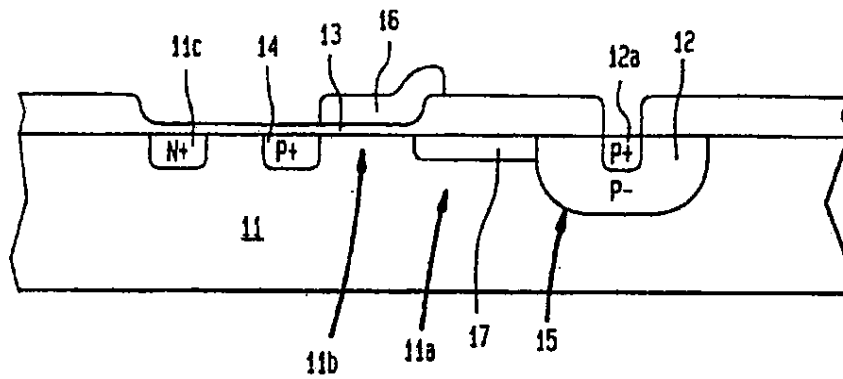


FIG. 1

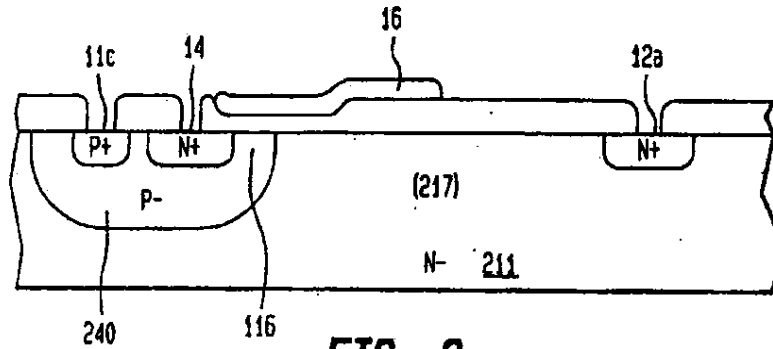


FIG. 2  
(PRIOR ART)

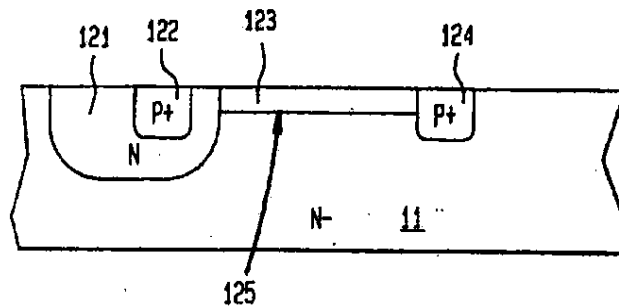


FIG. 3

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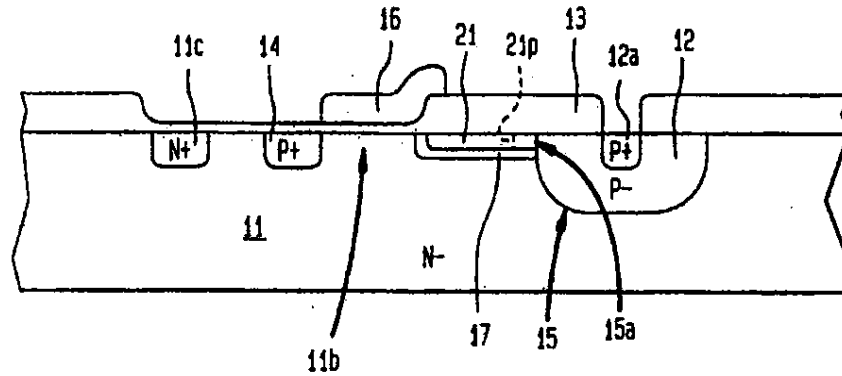


FIG. 4

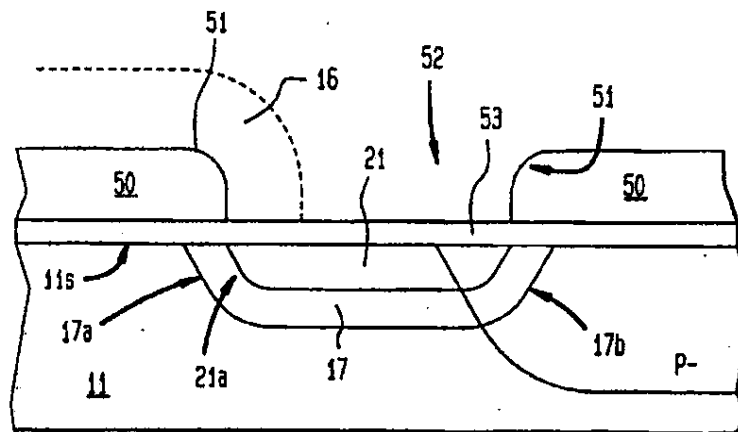


FIG. 5

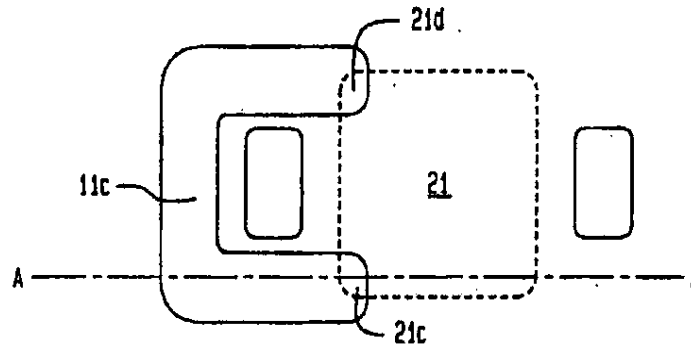
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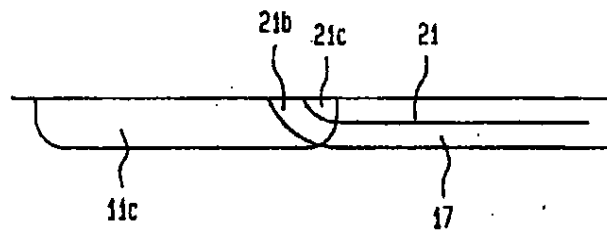
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**FIG. 6a**



**FIG. 6b**

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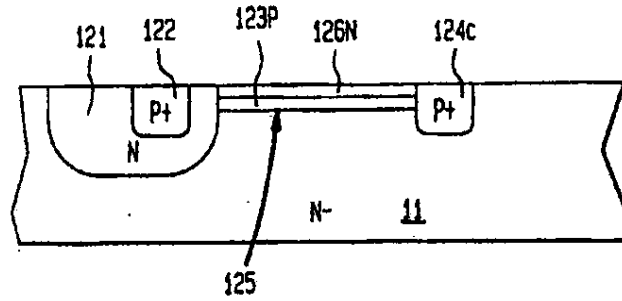


FIG. 7

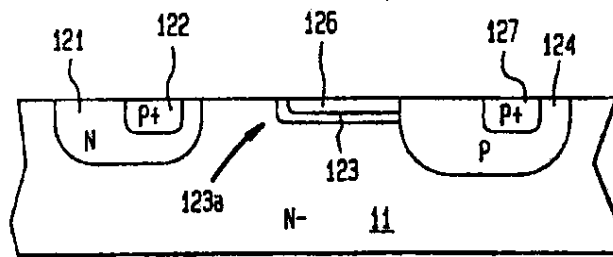


FIG. 8

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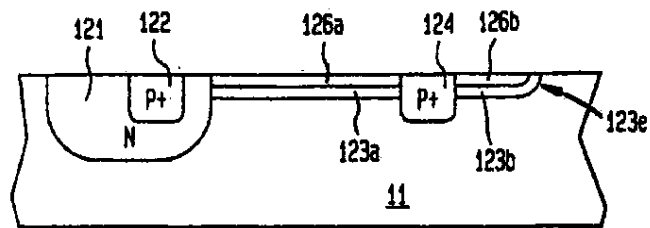


FIG. 9

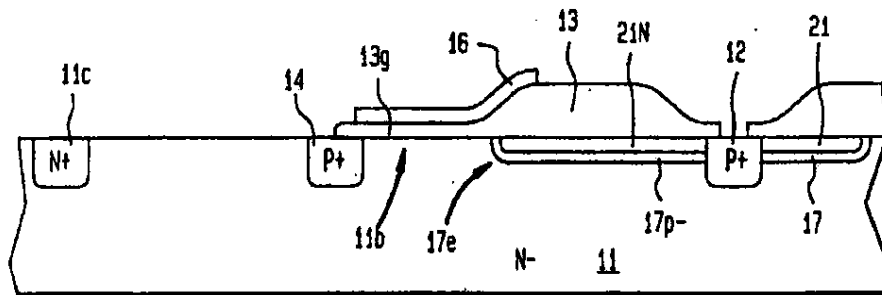


FIG. 10

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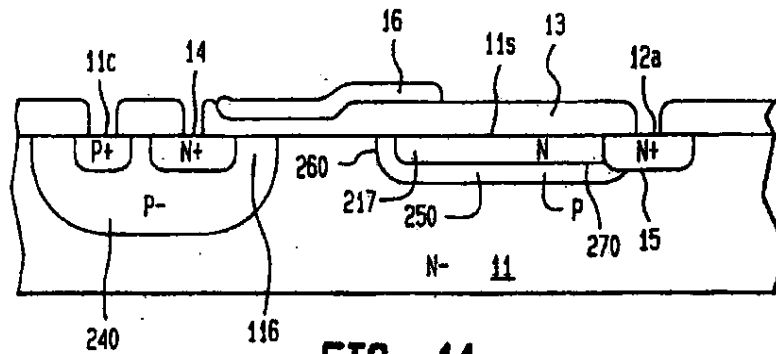


FIG. 11

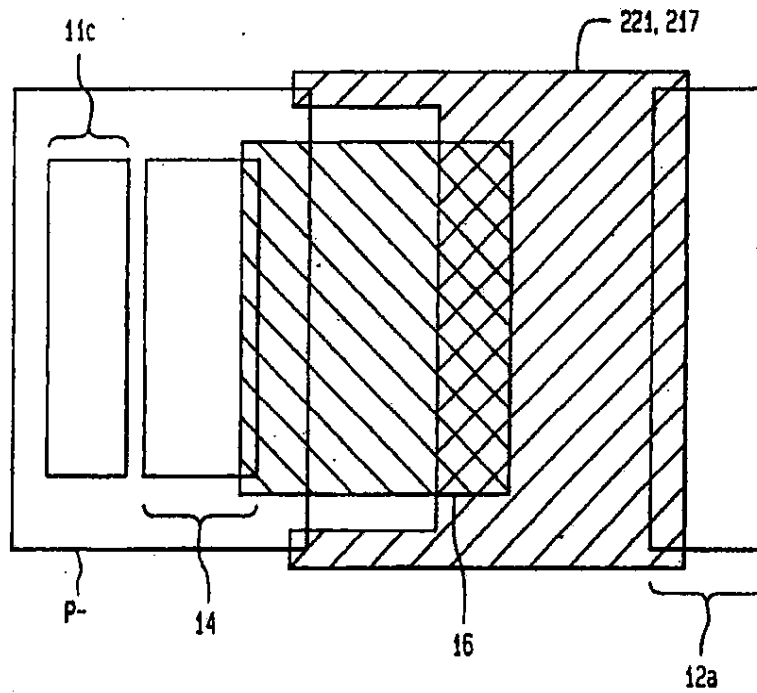


FIG. 12

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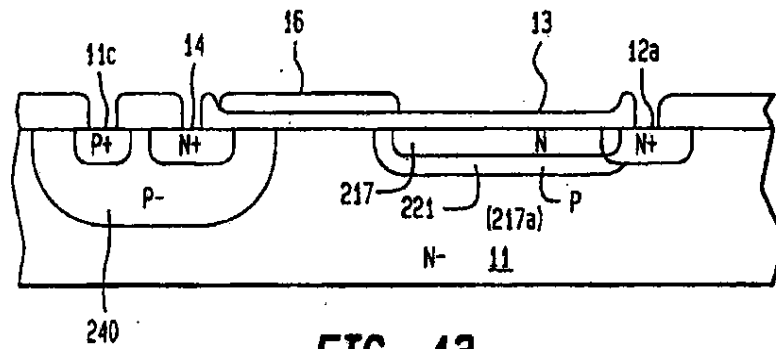


FIG. 13

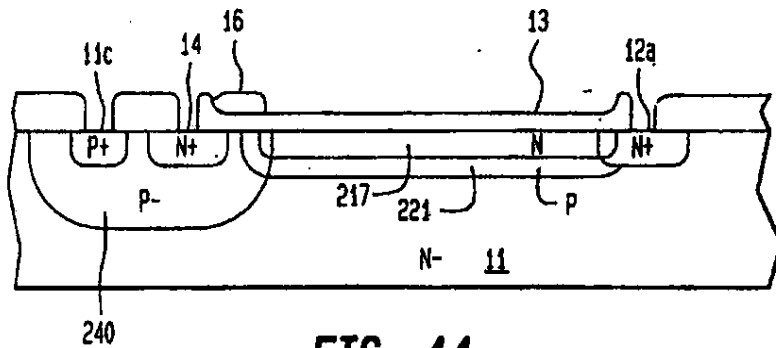


FIG. 14

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# HIGH VOLTAGE LATERAL SEMICONDUCTOR DEVICE

This is a continuation of application, Ser. No. 242,405, filed Sep. 8, 1988, now abandoned which, in turn, is a continuation-in-part of application, Ser. No. 831,384, filed Jan. 7, 1986, now U.S. Pat. No. 4,823,173, issued Apr. 18, 1989.

## FIELD OF THE INVENTION

The present invention relates to lateral semiconductor devices and an improved method of making lateral semiconductor devices. More specifically, the invention relates to high voltage lateral devices with reduced ON resistance and a method of making such devices.

Previous high voltage lateral devices include both MOS devices and bipolar transistors. For example, FIG. 1 illustrates a known structure which can be used as a high voltage lateral MOS device. This device is known as a lateral drift region MOS device and is dependent upon the drain-to-body junction 15 as the basic high voltage junction of the device. The drift region 17 is a P region along the top surface of the N- substrate 11 and is located so as to lie adjacent the P- drain region 12. The drift region 17 is used to connect the high voltage drain 12 to the gate 16 and source 14. The two contacts, drain contact 12, and body contact 11, are shown for completeness. In the operation of this circuit, the gate 16 and source 14 never assume large voltages relative to the body 11. The drift region 17 serves as a JFET channel with the portion 11<sub>a</sub> of body region 11 underlying the channel acting as a JFET gate. The JFET channel 17 is designed to totally deplete when the drain 12 is reverse biased to a voltage less than the voltage necessary to reach critical field in the channel-to-body depletion layer. This design preserves the effective high breakdown voltage of drain body junction 15. Also the source 14 and gate 16 (over the gate oxide 13) are safely shielded from the high drain body voltage by the pinched off JFET channel 17.

The resistance of the lateral drift region JFET channel 17 is in series with the resistance of the MOS channel 11<sub>a</sub>, consequently the total channel resistance of the device is the sum of these two individual resistances. The JFET channel, which must be quite long to sustain high drain body voltages, is often the larger of the two resistance terms. Thus it is desirable to find ways to reduce the resistance of the drift region so that devices of a given size can be made with smaller channel resistance.

FIG. 2 illustrates a known structure which can be used as a high voltage lateral DMOS (LDMOS) device. In this device, an N+ drain contact 12A is formed in the N- substrate 211 and an N+ source 14 and P+ body contact 11<sub>a</sub> are formed in a P- body region 240. The drift region 217 is an N- region along the top surface of the N- substrate 211 which connects the drain 12 to the gate 16 and source 14. In this high voltage device, the N- drift region 217 must be lightly doped to obtain high body 240 to drain breakdown.

The ON resistance of the LDMOS is approximately the sum of the channel resistance and the bulk resistance in the N- drift region 217. The lateral distance from the N+ drain 12 to the adjacent edge of the MOS channel 11<sub>a</sub> underlying the gate on the P- body 240 must be large to allow space for the reverse bias depletion layer which spreads from the body-to-drain junction into the

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lightly doped drain. This distance, along with the high N- resistivity contribute to the high drift region resistance, which is often much greater than the channel resistance. Thus, it is desirable to reduce the drift region resistance of the LDMOS device.

FIG. 3 shows a known structure which can be used as a lateral bipolar transistor. Another illustration of such a device is contained in FIG. 7 of U.S. Pat. No. 4,283,236 issued Aug. 11, 1981. Referring to FIG. 3, an N- substrate 11, has an N type emitter shield 121 formed therein and P+ emitter 122 and collector 124 formed as shown. Additionally, a P- drift region 123 is provided along the surface of the substrate between the collector 124 and the emitter shield 121. In the operation of this device, the total collector resistance is equal to the sum of the resistance across the drift region 123 plus the resistance of the P+ collector between the drift region and the collector contact. In order to provide devices of equal size having a lower collector resistance, it is desirable to find ways to reduce the resistance of the drift region.

In the operation of this device, the drift region extends the collector to the edge of the emitter shield, 121, so that the base width is just that small distance between the adjacent edges of the emitter, 121, and the drift region, therefore, providing improved frequency response.

At high base-collector voltages, the drift region, 123, depletes by JFET action with the N-base, 11, and N shield, 121, which is part of the base, acting as gate before critical field is reached just as for the MOS of FIG. 1. This preserves the high breakdown of the structure.

## SUMMARY OF THE INVENTION

The present invention provides a structure having a reduced channel resistance and a process capable of efficiently obtaining the structure of the invention. The reduction in channel resistance is accomplished by providing a top gate which is located between the lateral drift region of the prior art and the surface of the channel region and which may be in contact with the high voltage device region. This top gate allows the total channel doping to be increased because the top gate to channel depletion layer holds some additional channel charge when reverse biased in addition to that held by the bottom gate to channel depletion layer of the prior art structure. The ionized channel impurity atoms associated with this additional channel charge causes the reduction in channel resistance.

With respect to providing an improved LDMOS structure having a lower drift region resistance, a second drift region which is separated from the original drift region by a region of opposing conductivity is formed. The second drift region provides a conductive path which is in parallel with the original drift region thereby achieving the desired reduction in resistance. Because of the formation of the second drift region, the first enclosed drift region can now have a much higher doping than the second drift region which it replaces, while achieving the same breakdown voltage.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section of a known MOS device having typical ON resistance.

FIG. 2 is a cross section of a known LDMOS device having typical ON resistance.

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FIG. 3 is a cross section of a known bipolar transistor having typical collector resistance.

FIG. 4 is a cross section of an MOS device including the improved drift region and top gate of the invention.

FIG. 5 illustrates optimized process steps for obtaining the desired shape of the top gate and drift region of the invention.

FIGS. 6a and 6b are, respectively, a top view and a cutaway perspective view of the body contact extending through the top gate and drift region of the invention.

FIG. 7 is a cross section of a bipolar device made in accordance with one aspect of the invention.

FIG. 8 is a cross section of a bipolar device made in accordance with another aspect of the invention.

FIG. 9 is a cross section of a bipolar device made in accordance with a preferred aspect of the invention.

FIG. 10 is a cross section of an MOS device, including the lateral drift region and top gate of the invention, in a preferred embodiment.

FIG. 11 is a cross section of a LDMOS device made in accordance with a preferred embodiment of the invention.

FIG. 12 is a top view of the LDMOS device of FIG. 11.

FIG. 13 is a cross section of a LDMOS device made in accordance with another preferred embodiment of the invention.

FIG. 14 is a cross section of a LDMOS device made in accordance with still another preferred embodiment of the invention.

#### DETAILED DESCRIPTION OF THE INVENTION

The present invention is described herein with reference to the drawings for both MOS and bipolar applications. FIG. 4 shows an MOS device where P<sup>+</sup> drain contact 12<sub>a</sub> is formed in P<sup>-</sup> type drain 12, P<sup>+</sup> source 14 is formed in the N<sup>-</sup> body 11 and N<sup>+</sup> body contact 11<sub>c</sub> is provided in the N<sup>+</sup> body 11. The MOS channel region 11<sub>b</sub> is in the N<sup>-</sup> body 11 below the MOS gate 16. The N type top gate 21 is provided along the surface 11<sub>a</sub> of the body 11 above the P type drift region 17 which acts as a JFET channel. The lateral edge or peripheral edge of both the top gate 21 and drift region 17 extend to the drain-to-body junction 15 and preferably terminate at the junction 15. It is noted that situations may exist where the doping level in the top gate may be sufficiently high so as to render it desirable to provide a shorter top gate having a lateral extension which stops short of contacting the junction 15. In this case care should be taken to insure that any nondepleted portion of the top gate does not result in a breakdown of the top gate-to-drift region junction 17A. Proper doping of the top gate 21 will generally be a sufficient preventative step. Dashed line 21<sub>a</sub> designates the peripheral edge of top gate 21 in an embodiment where the top gate does not extend all the way to the junction 15.

The structure of FIG. 4 provides reduced ON resistance in the JFET channel 17 relative to the prior art lateral drift MOS device as shown in FIG. 1. The reduction in ON resistance is accomplished by providing a structure which can accommodate increased drift region doping without suffering from reduced body-to-drain breakdown. This is possible because of the provision of the top gate 21. The top gate-to-channel depletion layer which holds some channel charge when reverse biased, is in addition to the channel charge held by

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the bottom gate to channel depletion layer of the prior art. This additional channel charge, in the form of ionized channel impurity atoms, causes the reduction in channel resistance. It is possible to provide more than twice the doping level previously acceptable due to the additional ability to hold channel charge. Thus, for a drift region 17 having a doping of  $1 \times 10^{12}$  boron atoms per square centimeter in a bottom gate arrangement, the present invention will permit  $2 \times 10^{12}$  boron atoms per square centimeter. Thus, the ON resistance will be only half the ON resistance of the prior arrangement.

In order to optimize performance of the structure of the invention, the top gate 21 must be designed differently than an ordinary JFET gate. Top gate 21 should become totally depleted at a body-to-drain voltage of less than the breakdown voltage of the top gate-to-drain junction 15. Since top gate 21 is connected to body 11 (as shown in FIGS. 6A, 6B to be described below), the voltage at the top gate-to-drain junction 15<sub>a</sub> will equal the voltage of the body-to-drain junction 15 voltage and the top gate-to-drain breakdown voltage should be greater than the voltage at which top gate 21 becomes totally depleted. Additionally, the top gate 21 must totally deplete before the body 11 to channel 17 depletion layer reaches the top gate 21 to channel 17 depletion layer to thereby assure that a large top gate 21 to drain 12 voltage is not developed by punch-through action from the body 11. An ordinary JFET gate never totally depletes regardless of operating conditions.

In addition to the above described characteristics of the device of the invention, it is also necessary to insure that the channel of the JFET drift region 17 contacts the inversion layer MOS surface channel. This can be accomplished as shown in FIG. 5 where an implant mask 50 having a tapered edge 51 is provided over the body 11. An implant aperture 52 is provided in mask 50 at the location where the P drift region 17 and N top gate 21 are to be formed. The aperture 52 is shown as exposing the protective oxide 53. Ion implantation is not substantially affected by the oxide 53 due to the oxide thickness of only about 0.1-0.2 micrometers, yet the oxide provides surface passivation for the underlying body 11.

The drift region 17 is ion implanted and, because of the graduated thickness of the implant mask 50 (along the edge 51), the depth of the implanted drift region 17 is graduated or tapered. In the illustration, a fairly good rounding of the drift region 17 occurs at the peripheral edges or extremities 17<sub>a</sub>, 17<sub>b</sub> of the region 17. The curved extremity 17<sub>a</sub> is of interest because at this location the channel of the JFET drift region 17 contacts the surface 11<sub>a</sub> of body 11 beyond the end 21<sub>a</sub> of top gate 21 and is desirably beneath the gate 16 of the MOS device. The top gate 21 may be ion-implanted using the implant mask 50 but at an energy level which results in a shallower implantation. This tapered profile, particularly if curved, provides improved performance.

In a variation of this method, a diffusion process can be used to bring the JFET channel into contact with the surface of body 11, and hence insure that the JFET channel 17 will contact the inversion layer MOS surface channel (lateral drift region 17 and top gate 21 are diffused after initial introduction by ion implant). The doping levels and diffusion times are chosen such that the extremity 17<sub>a</sub> of JFET channel 17 diffuses beyond the end 21<sub>a</sub> of the top gate 21 and so that the end 17<sub>a</sub> reaches the surface 11<sub>a</sub> of body 11. In practice, this approach can be facilitated by choosing a top gate dop-

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ant which has a lower diffusion coefficient than that of the drift region dopant.

The formation of the drift region 17 and top gate 21 may be conveniently carried out by forming a mask over the gate oxide which is present in a lateral MOS application. The MOS gate may be utilized as one delineating edge of the implant for the drift region and top gate and a thick oxide portion surrounding a thinner oxide portion may form the remainder of the implant mask. The thinner oxide portion shall be located such that it extends from beneath the MOS gate to the drain and preferably overlaps the drain. The implant mask 50 illustrated in FIG. 5 is shown as having thin oxide portion 53 being surrounded by the implant mask 50. If the MOS gate 16 shown in dashed lines were used as a portion of the mask 50, the edge of the drift region and top gate would be self-aligned with the MOS gate as shown in dashed lines. Then, when diffused, the drift region will extend laterally to a point beneath the MOS gate, while the top gate 21 may be formed such that there is little or no lateral overlap with the MOS gate. The extent of lateral diffusion of the top gate is dependent upon the dopant material and processing temperatures following top gate implant. It is noted that there is a separation between the drift region and the source. This separation zone is the location where the MOS channel is located.

The top gate 21 will perform as previously described if it is tied to the body 11. Thus, the top gate 21 and the body which operates as the bottom gate of the JFET channel will be at equal potential. According to the invention, this may be accomplished in a particularly effective manner if the drift region 17 is widened to overlap with the body contact region 11. This is shown in FIG. 6a which shows the overlapping of the top gate 21 and the body contact 11, at the overlap regions 21c, 21d. In order for this arrangement to be effective, it is necessary that the body contact 11, have a higher dopant concentration than the JFET channel (or drift region) 17, as shown in FIG. 6b to insure that the body contact 11, forms a continuous region horizontally and/or vertically through the JFET channel and to the body region 11 from the top gate, 21.

FIG. 6b shows a cross section of the structure of FIG. 6a taken along dashed line A—A. The body 11 is provided with body contact 11c which is located such that the top gate 21 and drift region 17 can be conveniently extended to overlap the body contact 11c. The depth of body contact 11c may be made greater than the depth of region 17 such that a portion of the body contact 11c extends below region 17 and provides contact with the body 11. This arrangement provides a contact portion 21c where the top gate 21 is in contact with body contact 11c. Thus, as long as the body contact doping concentration in region 21c is sufficiently high to overcome the opposite doping in region 17, then a good connection of uniform conductivity type will be provided between the top gate 21 and the body 11, via contact region 11c. It is also noted that the body contact 11c extends laterally beyond the end of both of the top gate 21 and the drift region 17. The lateral extension of the contact 11c will also provide a structure which results in a good connection of uniform conductivity type from the top gate 21 to the body 11, again, provided that the doping of body contact 11c converts region 21c

Another area where the present invention finds application is in lateral bipolar transistors which employ a lateral drift region. The known structure of FIG. 3 may

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be improved by providing an N type top gate 126 as shown in FIG. 7. In this arrangement the N type gate 126 extends from the collector 124 to the emitter shield 121 along the surface of body 11. The operation of this device is enhanced by the same phenomenon as the lateral drift region of the previously described MOS device. As the base 11 becomes positive relative to the collector 124, the top gate-to-drift region depletion layer facilitates pinch-off of the drift region 123. However, as the base 11 becomes more negative, the top gate 126 contributes additional surface exposure to the drift region 123 and further enhances carrier transportation.

FIG. 8 shows an improvement over the arrangement shown in FIG. 7. In FIG. 8 the drift region 123 does not extend all the way over to the emitter shield 121. The curved end 123a of the drift region 123 contacts the top surface of body 11. It is noted that in this arrangement, the emitter shield 121 may be omitted.

An additional improvement shown in FIG. 8 is the use of a deep diffusion to form the collector 124 resulting in a significantly increased breakdown voltage. The deep diffusion step may be the same step used for forming the emitter, in which case the collector 124 shown in FIG. 7 would be deeper, or a separate collector implant and diffusion step may be employed and the collector contact 127 may then be formed simultaneously with the formation of the emitter 122. This improvement in junction breakdown voltage is equally obtainable, for example, at the body to drain junction in the MOS devices described previously.

A further extension of the invention which may be used to increase base-to-collector breakdown voltage for a PNP device is shown in FIG. 9. In addition to the provision of the N type top gate 126, over the P- drift region 123a, the top gate 126a and drift region 123A are enlarged to surround the collector 124 and a curved edge 123b is provided at the periphery of the enlarged portion 123b of the drift region 123A. This enlarged portion is designated by reference numerals 123b for the drift region and 126b for the top gate. The collector 124 to base 11 breakdown voltage is increased relative to alternative arrangements because of mitigation of the breakdown reduction due to the junction curvature. The top gate 126c extends to the emitter shield 121 as does the drift region 123a. The P+ emitter 122 is formed in the N+ type emitter shield 121.

FIG. 10 illustrates an extension of the invention with respect to a P channel MOS device similar to the improvement described with respect to the bipolar device shown in FIG. 9. For the MOS device, the drain 12 is surrounded by the P- drift region 17 and N type top gate 21. Around the entire periphery of the drift region 17 there is a curved portion 17c which rounds up to the surface of the N- substrate 11 to insure that the JFET channel in the drift region 17 contacts the MOS channel 11b under the MOS gate 16. The drift region 17 extends outward from the entire perimeter of the drain 12. This arrangement mitigates the breakdown reduction due to junction curvature. The P+ source 14 and N+ body contact 11c are shown as is the dielectric 13 which serves as the gate oxide 13c beneath the MOS gate 16.

In both the arrangements shown in FIG. 9 and FIG. 10, the planar diode breakdown improvement created by the drift region acting as a surface layer of the same conductivity type as the collector in FIG. 9 and drain in FIG. 10 and extending out from the perimeter of the collector and drain can be implemented by a single series of process steps. According to the invention, a

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common set of process steps produces both a suitable breakdown improvement layer and an improved drift region. The breakdown improvement layer is a two layer component.

A further extension of the invention is illustrated in FIG. 11 which shows an LDMOS device where N<sup>+</sup> drain contact 12<sub>a</sub> is formed in an N<sup>-</sup> type substrate and an N<sup>+</sup> source 14 and P<sup>+</sup> body contact 11<sub>a</sub> are formed in a P<sup>-</sup> type body region 240. The DMOS channel region 11<sub>b</sub> is in the P<sup>-</sup> body 240 below the DMOS gate 16. The N type first drift region 217 is provided along the surface 11<sub>a</sub> of the substrate 11 above a P<sup>-</sup> type separation region 250. A second drift region 217<sub>a</sub> exists in the substrate 11 underneath the P<sup>-</sup> type separation region. The lateral edge of both the first drift region 217 and the separation region 250 extend from the gate 16 to the N<sup>+</sup> drain contact 12<sub>a</sub>.

The structure in FIG. 11 provides reduced ON resistance by way of the second (surface) drift region 217<sub>a</sub> relative to the (deeper) prior art lateral first drift region 217<sub>a</sub> device, refer to above in FIG. 2. To illustrate this, consider an example in which the N<sup>-</sup> region 11 has a doping of  $1 \times 10^{14}$  ions cm<sup>-3</sup>. The top gate layer 217 has an integrated doping of about  $1 \times 10^{12}$  ions cm<sup>-2</sup> and is preferably not more than two microns thick while maintaining full breakdown. The thickness of the N and P layers 217, 250 together is preferably less than ten microns and can be less than one micron. The same integrated doping in the N<sup>-</sup> body 11 requires a thickness of 100 microns. Thus, the N and P layers 217, 250 respectively consume only a small fraction of the N<sup>-</sup> thickness required to provide doping equal to that portion of the N layer of the prior art device.

The lateral spacing between the drain contact 12<sub>a</sub> and the channel 11<sub>b</sub> in the device described above would be approximately 30 microns. In such a device, even if a full 100 micron thick N<sup>-</sup> body 11 were provided, it would have a higher resistance than the N<sup>-</sup> first drift region 217 provided according to the invention. This is because the average path length of current flowing from the drain contact 12A down through the thick N<sup>-</sup> body 11 and back up to the surface edge of the channel at the drain-to-body junction would be greater than the direct path through the N<sup>-</sup> first drift region.

Maximum breakdown is achieved in the invention by providing doping densities of the N and P layers 217, 250 such that they become totally depleted before breakdown is reached at any point along the junctions which they form with adjoining regions and before breakdown is reached at the junction between them. To insure that this occurs, the N region 217 should have an integrated doping not exceeding approximately  $1 \times 10^{12}$  ions cm<sup>-2</sup> and the P region 250 should have a higher integrated doping not exceeding about  $1.5$  to  $2 \times 10^{12}$  ions cm<sup>-2</sup>.

To insure proper depletion of the P and N regions 250, 217, they must have the proper voltages applied. The N layer bias is achieved by connecting the N first drift region 217 to the higher concentration N<sup>+</sup> drain contact 12<sub>a</sub> by overlapping the N first drift region 217 and drain contact 12<sub>a</sub>. The P region 250 bias is achieved by overlapping the P region 250 with the P<sup>-</sup> body 240 at least at one end of the channel, thereby applying the body voltage to the P layer 250. This is illustrated in FIG. 12.

With this structure and choice of doping levels, the desired results are achieved. When a reverse bias voltage is applied to the drain-to-body junction 15, the same

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reverse bias appears on both the PN<sup>-</sup> junction 260 and the PN junction 270. Depletion layers spread up into the N first drift region 217 and down into the N<sup>-</sup> body 11 from the P layer 250. In a preferred embodiment, the P and N first drift region dopings are chosen such that the N layer 217 becomes totally depleted at a lower voltage than that at which the P layer 250 becomes totally depleted. This insures that no residual undepleted portion of the N layer 217 is present which could reduce breakdown voltage.

As a result of the invention, the improved DMOS device provides a reduced resistance current path in the drain which does not depend on the N<sup>-</sup> doping. This allows the N<sup>-</sup> doping to be reduced to achieve a desired breakdown voltage with good manufacturing margin, while maintaining desirable low drift region resistance. In a multi-device process which includes LDMOS devices, the N<sup>-</sup> region can be adjusted to achieve the desired characteristics of one or more of the other device types, while the N first drift region 217 sets the drift region 217 resistance of the LDMOS.

Another embodiment of the DMOS invention is illustrated in FIG. 13, where the N and P regions 217, 221 are self-aligned to the gate 16 by using the gate 16 as a mask. An advantage of this structure is that N and P regions can be defined by the uncovered thin oxide area which extends from gate edge to overlap the drain contact. This embodiment requires no explicit mask step to delineate the location where the N and P regions are formed.

Still another embodiment, as illustrated in FIG. 14, provides no gap between the P<sup>-</sup> body 240 and the P region 221 adjacent to the channel edge. The absence of the gap prevents current from flowing in the N<sup>-</sup> body 11; so the entire drift region current path is in the N first drift region 217. Elimination of the gap also allows the device structure to be made smaller. As with the other structure, the N and P regions may be self-aligned to the gate edge, as illustrated in FIG. 14, or not self-aligned. They may also be covered by thick or thin oxide as a design option.

A preferred feature of the present invention provides that the body or substrate regions 11 shown in the FIGS. 3, 4, 6, 7, 8, 9, 11, 13 and 14 are designed to be dielectrically or self-isolated regions. In contrast with the typical RESERF type of devices in which the bottom isolation junction plays a central role in the action of the device, the present invention contemplates that the isolation junction does not contribute to the depletion of the drift or top gate regions which are taught to be totally depleted. Prior art RESERF devices such as that described in U.S. Pat. No. 4,300,150 to Colak always require the substrate to be part of such depletion whereby the substrate must assume the most negative voltage in the device because of its role as one side of the isolation junction. As a result of this bias on the substrate or body region, the prior art RESERF type devices are susceptible to punch through from the device region through the epitaxial layer to the substrate. As a result of the present invention not having the substrate as part of the depletion mechanism, the invention can more effectively provide high voltage protection while not increasing the resistance of the channel path. Although the figures illustrate a nonisolating structure or self-isolated structure, it is understood that the invention applies equally well to dielectrically or junction isolated substrates.

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While the present invention has been described with respect to several preferred manners of implementing the invention, it is to be understood that the claims appended hereto are intended to cover the invention in its broadest sense and are not to be limited to the specific implementations disclosed.

What is claimed is:

1. A semiconductor device comprising:
  - a semiconductor body of a first conductivity type having a first surface;
  - a first semiconductor region of a second conductivity type formed in a first portion of said first surface of said semiconductor body, and defining a first PN junction with said semiconductor body;
  - a second semiconductor region of said first conductivity type formed in a surface portion of said first semiconductor region and defining therewith a second PN junction, said second PN junction being spaced apart from said first PN junction by material of said first semiconductor region therebetween;
  - a third semiconductor region of said first conductivity type formed in a second surface portion of said semiconductor body, spaced apart from said first surface portion by a third surface portion thereof;
  - a fourth semiconductor region of said second conductivity type formed in a first surface part of said third surface portion of said semiconductor body spaced apart from said first surface portion of said semiconductor body by a second surface part of said third surface portion thereof and defining with said semiconductor body a third PN junction, said fourth semiconductor region being connected to said first semiconductor region and being contiguous with said third semiconductor region;
  - a fifth semiconductor region of said first conductivity type, and having an impurity concentration greater than that of said semiconductor body, formed in said fourth semiconductor region and defining therewith a fourth PN junction, said fifth semiconductor region being contiguous with said third semiconductor region;
  - an insulator layer formed on said first surface of said semiconductor body; and
  - a gate electrode formed on said insulator layer so as to overlie said second surface part of said third surface portion of said semiconductor body and material of said first and fourth semiconductor regions, that portion of said first semiconductor region lying beneath said gate electrode serving as a channel region of said device, said gate electrode having a gate voltage applied to induce a conductive channel through said first semiconductor region therebeneath; and wherein
- when said device is reverse-biased, a first depletion region extends from said fourth PN junction into said fourth semiconductor region and said semiconductor body, and a second depletion region extends from said fifth PN junction into said fifth semiconductor region and said fourth semiconductor region;
- said semiconductor body having a first ON resistance in a first current flow path therethrough between said second and third semiconductor regions, and said fifth semiconductor region providing a second ON resistance in a second current flow path along the surface of said semiconductor body from said second semiconductor region through said channel

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and said fourth and fifth semiconductor regions to said third semiconductor region, so that said fifth semiconductor region serves to provide a current flow path in parallel with said first current flow path, thereby effectively reducing the total ON resistance of the overall current flow path between said second and third semiconductor regions.

2. A semiconductor device according to claim 1, wherein a peripheral edge of said gate electrode is aligned with a peripheral edge of said fifth semiconductor region.

3. A semiconductor device according to claim 1, wherein said fourth semiconductor region overlaps said first semiconductor region.

4. A semiconductor device according to claim 1, wherein the impurity concentration said fifth semiconductor region is such that said fifth semiconductor region is completely depleted by said second depletion region at a reverse bias less than that at which said first and second depletion regions come together within and punch through said fourth semiconductor region.

5. A semiconductor device comprising:

- a semiconductor body of a first conductivity type having a first surface;

- a first semiconductor region of a second conductivity type formed in a first portion of said first surface of said semiconductor body, and defining a first PN junction with said semiconductor body;

- a second semiconductor region of said first conductivity type formed in a surface portion of said first semiconductor region and defining therewith a second PN junction, said second PN junction being spaced apart from said first PN junction by material of said first semiconductor region therebetween;

- a third semiconductor region of said first conductivity type formed in a second surface portion of said semiconductor body, spaced apart from said first surface portion by a third surface portion thereof;

- a fourth semiconductor region of said second conductivity type formed in said third surface portion of said semiconductor body and defining with said semiconductor body a third PN junction, said fourth semiconductor region being connected to said first semiconductor region and being contiguous with said first and third semiconductor regions;

- a fifth semiconductor region of said first conductivity type, and having an impurity concentration greater than that of said semiconductor body, formed in said fourth semiconductor region and defining therewith a fourth PN junction, said fifth semiconductor region being contiguous with said first and third semiconductor regions;

- an insulator layer formed on said first surface of said semiconductor body; and

- a gate electrode formed on said insulator layer so as to overlie material of said first and fourth semiconductor regions, that portion of said first semiconductor region lying beneath said gate electrode serving as a channel region of said device, said gate electrode having a gate voltage applied to induce a conductive channel through said first semiconductor region therebeneath; and wherein

- when said device is reverse-biased, a first depletion region extends from said fourth PN junction into said fourth semiconductor region and said semiconductor body, and a second depletion region extends from said fifth PN junction into said fifth semiconductor region

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ductor region and said fourth semiconductor region.

6. A semiconductor device according to claim 5, wherein the impurity concentration said fifth semiconductor region is such that said fifth semiconductor region is completely depleted by said second depletion region at a reverse bias less than that at which said first and second depletion regions come together within and punch through said fourth semiconductor region.

7. A semiconductor device comprising:

a semiconductor body of a first conductivity type having a first surface;

a first semiconductor region of a second conductivity type formed in a first portion of said first surface of said semiconductor body, and defining a first PN junction with said semiconductor body;

a second semiconductor region of said second conductivity type formed in a second surface portion of said semiconductor body, spaced apart from said first surface portion by a third surface portion thereof and defining a second PN junction with said semiconductor body;

a third semiconductor region of said second conductivity type formed in a first surface part of said third surface portion of said semiconductor body spaced apart from said first surface portion of said semiconductor body by a second surface part of said third surface portion thereof and defining with said semiconductor body a third PN junction, said third semiconductor region being contiguous with said second semiconductor region;

a fourth semiconductor region of said first conductivity type, and having an impurity concentration greater than that of said semiconductor body, formed in said third semiconductor region and defining therewith a fourth PN junction;

an insulating layer formed on said first surface of said semiconductor body; and

a gate electrode formed on said insulator layer so as to overlie said second surface part of said third surface portion of said semiconductor body, that portion of said semiconductor body lying beneath said gate electrode serving as a channel region of said device, said gate electrode being applied with a gate voltage for inducing a conductive channel through said channel region;

said device being reverse-biased, so that a first depletion region extends from said third PN junction into said third semiconductor region and said semiconductor body and a second depletion region extends from said fourth PN junction into said third semiconductor region and said fourth semiconductor region;

said semiconductor body having a first ON resistance in a first current flow path therethrough between said first and second semiconductor regions, and said fourth semiconductor region providing a second ON resistance, less than said first ON resistance, in a second current flow path along the surface of said semiconductor body from said first semiconductor region through said channel and said third and fourth semiconductor regions to said second semiconductor region, so that said fourth semiconductor region serves to provide a reduced resistance current flow path in parallel with said first current flow path, thereby effectively reducing the total ON resistance of the overall current

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flow path between said first and second semiconductor regions; and

wherein the impurity concentration said fourth semiconductor region is such that said fourth semiconductor is completely depleted by said second depletion region at a reverse bias less than that at which said first and second depletion regions come together within and punch through said third semiconductor region.

8. A high voltage MOS transistor comprising:

a semiconductor substrate of a first conductivity type having a surface,

a pair of laterally spaced source and drain pockets of semiconductor material of a second conductivity type within the substrate and adjoining the substrate surface,

an extended drain region of the second conductivity type extending laterally each way from said drain pocket to surface-adjoining positions,

a surface adjoining, top layer of material of the first conductivity type on top of an intermediate portion of the extended drain region between the drain pocket and the surface-adjoining positions,

said top layer of material and said substrate being subject to application of a reverse-bias voltage,

an insulating layer on the surface of the substrate and covering at least that portion between the source pocket and the nearest surface-adjoining position of the extended drain region, and

a gate electrode on the insulating layer and electrically isolated from the substrate region thereunder which forms a channel laterally between the source pocket and the nearest surface-adjoining position of the extended drain region, said gate electrode controlling by field-effect the flow of current thereunder through the channel.

9. A high voltage MOS transistor according to claim 8, wherein said extended drain region has an impurity concentration greater than  $1 \times 10^{12} \text{ cm}^{-2}$ .

10. A high voltage MOS transistor according to claim 8, further including an ohmic contact region of said first conductivity type formed in a surface adjoining portion of said semiconductor substrate, said ohmic contact region overlapping said top layer of material.

11. A high voltage MOS transistor comprising: semiconductor material of a first conductivity type having a surface,

a pair of laterally spaced source and drain pockets of semiconductor material of a second conductivity type within the substrate and adjoining the surface of said semiconductor material,

an extended drain region of the second conductivity type extending laterally from said drain pocket to a surface-adjoining position,

a surface adjoining top layer of material of the first conductivity type on top of an intermediate portion of the extended drain region between the drain pocket and said surface-adjoining position,

said top layer of material and said semiconductor material being subject to application of a reverse-bias voltage,

an insulating layer on the surface of said semiconductor material and covering at least that portion between the source pocket and the nearest surface-adjoining position of the extended drain region, and

a gate electrode on the insulating layer and electrically isolated from a semiconductor material re-

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gion thereunder containing a channel that extends laterally between the source pocket and the nearest surface-adjointing position of the extended drain region, said gate electrode controlling by field-effect the flow of current thereunder through the channel.

12. A high voltage MOS transistor according to claim 11, wherein said extended drain region extends in a plurality of different directions from said drain pocket to respective plural surface adjoining positions.

13. A high voltage MOS transistor according to claim 11, wherein said extended drain region surrounds said drain pocket and extends to a surrounding surface adjoining position.

14. A high voltage MOS transistor according to claim 11, wherein said drain pocket comprises a first relatively deep pocket of a first impurity concentration and a second relatively shallow pocket formed in a surface portion of said first relatively deep pocket and having a second impurity concentration greater than said first impurity concentration and providing a drain contact region.

15. A high voltage MOS transistor according to claim 11, wherein said extended drain region has an impurity concentration greater than  $1 \times 10^{12} \text{ cm}^{-2}$ .

16. A high voltage MOS transistor according to claim 11, further including an ohmic contact region of said first conductivity type formed in a surface adjoining portion of said semiconductor material, said ohmic contact region overlapping said top layer of material.

17. A high voltage field effect transistor device comprising:

semiconductor material of a first conductivity type having a surface;

a source region of a second conductivity type formed in a first surface portion of said semiconductor material;

a drain region of said second conductivity type formed in a second surface portion of said semiconductor material spaced apart from said first surface portion by a third surface portion therebetween;

an extended drain region of said second conductivity type extending from said drain region beneath a first portion of said third surface portion of said semiconductor material, to adjoin a second portion of said third surface portion of said semiconductor material, spaced apart from said said second surface portion of said semiconductor material, by said first portion of said third surface portion of said semiconductor material;

a surface region of said first conductivity type formed in said first portion of said third surface portion of said semiconductor material;

an insulating layer disposed on said surface of said semiconductor material, so as to overlie a third portion of said third surface portion of said semiconductor material between the second portion of said third surface portion of said semiconductor material and said first surface portion of said semiconductor material; and

a gate electrode disposed on that portion of said insulating layer overlying said third portion of said third surface portion of said semiconductor material, and wherein said surface region and said semiconductor material are subject to the application of a reverse bias voltage.

18. A high voltage field effect transistor device according to claim 17, wherein said extended drain region

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extends laterally in a plurality of different directions from said drain region to adjoin said second portion of said third surface portion of said semiconductor material and to adjoin a fifth surface portion of said semiconductor material.

19. A high voltage field effect transistor device according to claim 17, wherein said extended drain region surrounds said drain region and extends to a surrounding surface-adjointing portion of said semiconductor material.

20. A high voltage field effect transistor device according to claim 17, wherein said drain region comprises a first relatively deep region of a first impurity concentration and a second relatively shallow region formed in a surface portion of said first relatively deep region and having a second impurity concentration greater than said first impurity concentration and providing a drain contact region.

21. A high voltage field effect transistor device according to claim 17, wherein said extended drain region has an impurity concentration greater than  $1 \times 10^{12} \text{ cm}^{-2}$ .

22. A high voltage field effect transistor device according to claim 17, further including an ohmic contact region of said first conductivity type formed in a surface adjoining portion of said semiconductor material, said ohmic contact region overlapping said surface region.

23. An integrated MOS/JFET transistor device comprising an insulated gate field effect transistor and a double-sided junction field effect transistor integrated together in semiconductor substrate which contains a source region, and a drain region, and a dual channel path formed in said semiconductor material between said source and drain regions, said dual channel path comprising an insulated gate-controlled channel region having a first conductivity type in the presence of a channel-inducing gate voltage, said insulated gate controlled channel region being contiguous with a double-sided junction channel region of said first conductivity type, and wherein said source region adjoins said insulated gate-controlled channel region and said drain region adjoins said double-sided channel region.

24. An integrated MOS/JFET transistor device according to claim 23, wherein said insulated gate-controlled channel region comprises a surface portion of said semiconductor material adjoining said source region, and wherein said double-sided junction channel region comprises an extended drain region extending laterally from said drain region beneath a top gate region to said surface portion of said semiconductor material, an underlying portion of said semiconductor material extending beneath and adjoining said extended drain region and forming a bottom gate, said top gate region and said bottom gate forming respective PN junctions with said double-sided junction channel region.

25. An integrated MOS/JFET transistor device according to claim 23, wherein said extended drain region and said double-sided junction channel region surround said drain region and extend to a surrounding surface-adjointing position.

26. An integrated MOS/JFET transistor device according to claim 23, wherein said extended drain region and said double, wherein said drain region comprises a first relatively deep region of a first impurity concentration and a second relatively shallow region formed in a surface portion of said first relatively deep region and having a second impurity concentration greater than

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said first impurity concentration and providing a drain contact region.

27. An integrated MOS/JFET transistor device according to claim 23, wherein said extended drain region and said double, further including an ohmic contact region of said first conductivity type formed in a surface adjoining portion of said semiconductor material, said ohmic contact region overlapping said top gate.

28. An integrated MOS/JFET transistor device according to claim 23, wherein said extended drain region has an impurity concentration greater than  $1 \times 10^{12} \text{ cm}^{-2}$ .

29. A high voltage MOS transistor comprising: semiconductor material of a first conductivity type having a surface;

source and drain regions of a second conductivity type adjoining spaced apart portions of the surface of said semiconductor material;

an extended drain region of said second conductivity type extending laterally from said drain region through said semiconductor material to a surface-adjoining portion of the surface of said semiconductor material;

a top gate semiconductor layer of said first conductivity type adjoining said drain region and adjoining said extended drain region along the surface of said semiconductor material to said surface-adjoining portion of the surface of said semiconductor material, said top gate semiconductor layer and said semiconductor material being subject to the application of a reverse-bias voltage;

an insulating layer on the surface of the semiconductor material and covering at least that portion of the surface of said semiconductor material between said source region and said surface-adjoining portion of said extended drain region; and

a gate electrode disposed on said insulating layer and being electrically isolated from that portion of the surface of said semiconductor material thereunder which forms a channel laterally between said source region and said surface-adjoining portion of said extended drain region, said gate electrode controlling, by field-effect, the flow of current thereunder through said channel.

30. A high voltage MOS transistor according to claim 29, wherein said extended drain region extends laterally each way from said drain region to surface-adjoining portions of the surface of said semiconductor material, and wherein said top gate semiconductor layer extends laterally in a plurality of different directions from said drain region and adjoins said extended drain region along the surface of said semiconductor material to said surface-adjoining portions of the surface of said semiconductor material.

31. A high voltage MOS transistor according to claim 29, wherein said extended drain region surrounds said drain region and extends to a surrounding surface adjoining position.

32. A high voltage MOS transistor according to claim 29, wherein said drain region comprises a first relatively deep region of a first impurity concentration and a second relatively shallow region formed in a surface portion of said first relatively deep region and having a second impurity concentration greater than said first impurity concentration and providing a drain contact region.

33. A high voltage MOS transistor according to claim 29, wherein said extended drain region has an impurity concentration greater than  $1 \times 10^{12} \text{ cm}^{-2}$ .

34. A high voltage MOS transistor according to claim 29, further including an ohmic contact region of said

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first conductivity type formed in a surface adjoining portion of said semiconductor material, said ohmic contact region overlapping said top gate layer.

35. A high voltage diode comprising: semiconductor material of a first conductivity type having a surface,

a first, surface-adjoining region of a second conductivity type;

a second surface-adjoining region of said first conductivity type spaced apart from said first, surface-adjoining region;

a third region of said second conductivity type extending laterally from said first, surface-adjoining region; and

a fourth, surface-adjoining region of said first conductivity type overlying an intermediate portion of said third, laterally extending and surface-adjoining region.

36. A high voltage diode according to claim 35, wherein said third region surrounds said first, surface-adjoining region and extends to a surrounding surface adjoining position.

37. A high voltage diode according to claim 35, wherein said first region comprises a first relatively deep region of a first impurity concentration and a second relatively shallow region formed in a surface portion of said first relatively deep region and having a second impurity concentration greater than said first impurity concentration.

38. A high voltage diode according to claim 35, wherein said third region has an impurity concentration greater than  $1 \times 10^{12} \text{ cm}^{-2}$ .

39. A lateral bipolar transistor having a high voltage base-collector diode comprising:

semiconductor material of a first conductivity type having a surface and forming a base of said bipolar transistor,

a first, surface-adjoining collector region of a second conductivity type forming a base-collector junction with said semiconductor material;

a second surface-adjoining base region of said first conductivity type spaced apart from said first, surface-adjoining collector region;

a third, extended collector region of said second conductivity type extending laterally from said first, surface-adjoining collector region, so that said base-collector junction extends laterally from said first, surface adjoining collector region;

a fourth, surface-adjoining region of said first conductivity type overlying an intermediate portion of said third, laterally extending and surface-adjoining extended collector region; and

a fifth, surface-adjoining emitter region of said second conductivity type formed in said second surface-adjoining base region and defining therewith an emitter-base junction.

40. A lateral bipolar transistor according to claim 39, wherein said third region surrounds said first, surface-adjoining region and extends to a surrounding surface adjoining position.

41. A lateral bipolar transistor according to claim 39, wherein said first region comprises a first relatively deep region of a first impurity concentration and a second relatively shallow region formed in a surface portion of said first relatively deep region and having a second impurity concentration greater than said first impurity concentration.

42. A lateral bipolar transistor according to claim 39, wherein said third, extended collector region has an impurity concentration greater than  $1 \times 10^{12} \text{ cm}^{-2}$ .

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**CERTIFICATE OF SERVICE**

I hereby certify that on the 19<sup>th</sup> day of January, 2006, the attached **NOTICE OF DEPOSITION AND SUBPOENA OF JAMES BEASOM PURSUANT TO FEDERAL RULE OF CIVIL PROCEDURE 45** was served upon the below-named counsel of record at the address and in the manner indicated:

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*/s/ Lauren E. Maguire*

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